PROCESS OF MAKING POROUS ELECTRODES

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BACKGROUND

In the field of electrochemical devices, electrode composition, morphology, and/or architecture can have significant influence on device performance. Fabrication processes, which can be overly complex, are also of concern with regard to device quality, facility cost, and/or device cost. In one example of how device performance can be influenced by electrode properties, the presence of water in electrodes, which water can be introduced during fabrication, can significantly reduce the energy density and lifetime of lithium-ion batteries. Furthermore, transport paths can determine battery power and recharge rates making porosity and conductivity important electrode properties. As an example of how porosity affects performance, current methods for production of lithium ion batteries for automotive transportation applications require about 40% porosity in the electrode to facilitate rapid discharge rates and hence high power. Common fabrication processes often utilize pore formers that can be hard to remove, can generate significant waste products, and/or can introduce process steps having high potential to reduce device quality and increase failure rates. Examples of such pore formers include, commonly, N-methylpyrrolidinone (NMP) and, less commonly, dibutylphthalate (DBP). These materials play no active role in performance of the lithium battery and must be extracted from the electrode prior to cell assembly. That extraction adds substantially to the complexity and cost of the fabrication process and can reduce the performance of the electrochemical device. Accordingly, a need exists for methods, compositions, and apparatuses to prepare porous electrodes for electrochemical devices.

SUMMARY

Embodiments of the present invention include methods and compositions for preparing porous electrodes as contained in electrochemical devices. In particular, electrochemical devices can include, but are not limited to, lithium ion batteries, which includes lithium ion polymer batteries, having an electrolyte composition. Preferably, the electrolyte composition is a liquid, gel, or other fluid. The methods are characterized by depositing on a substrate a feedstock comprising a soluble pore former. Deposition of the feedstock on the substrate initiates formation of an electrode. Some time before, during, or after formation of the electrode, the method involves precipitating at least a portion of the soluble pore former from the feedstock. This precipitation causes that portion of the soluble pore former to exist as a solid phase within the electrode. The pore former can later be dissolved from the electrode using at least a portion, or a constituent, of the electrolyte composition. Removal of the pore former from the electrode leaves voids that constitute pores in the electrodes. In some embodiments, precipitation of the soluble pore former can occur by evaporating at least a portion of the feedstock. Alternatively precipitation can occur by altering the temperature of the feedstock. More specifically, the temperature can be decreased. Additional methods for causing precipitation of the soluble pore former can be suitable and are based on the concentration of the soluble pore former in feedstock and on the conditions imposed on the feedstock.

In some embodiments, the soluble pore former forms a two-phase system with at least one constituent of the electrolyte composition. In specific instances the soluble pore former can comprise ethylene carbonate. In such instances the feedstock can further comprise dimethyl carbonate, diethyl carbonate, propylene carbonate, or a combination of these electrolyte constituents. Preferably the feedstock does not contain materials that are not also so substantially contained in the lithium ion battery. While many of the examples and embodiments described herein involve feedstock constituents that perform a function in the lithium ion battery, an active role is not a requirement. In other words, the feedstock constituents, which can include a pore former and the solvent for the pore former, can be inert so long as their presence does not negatively influence the performance of the battery and/or complicate the fabrication.

In preferred embodiments the feedstock is an ink for ink jet printing. Accordingly, the step of depositing the ink on the substrate is accomplished by printing with an ink jet printer on the substrate.

Another aspect of the present invention encompasses a feedstock composition for preparing the porous electrodes. The feedstock composition can be characterized by a pore former that forms a two-phase system with at least one constituent of an electrolyte composition of a lithium ion battery. The feedstock composition should not contain substantially any materials that are not also contained in the lithium ion battery. A specific example of a pore former can include, but is not limited to, ethylene carbonate. In instances where the pore former is ethylene carbonate, the electrolyte composition can comprise dimethyl carbonate, diethyl carbonate, propylene carbonate, a combination of these or other solvents useful as the electrolyte In some embodiments the pore former is also a constituent of the electrolyte composition. Alternatively the pore former can be an inert constituent of the lithium battery. Additional pore formers, which form a two-phase system with at least one constituent of the electrolyte composition of the lithium ion battery, exist and can suitably replace ethylene carbonate. However, in preferred embodiments, the alternative pore formers are not sacrificial pore formers in that they must ultimately be removed and in that they are not substantially contained in the lithium ion battery. Specifically, the feedstock should not contain NMP or DBP as pore formers.

The purpose of the foregoing summary is to enable the United States Patent and Trademark Office and the public generally, especially the scientists, engineers, and practitioners in the art who are not familiar with patent or legal terms or phraseology, to determine quickly from a cursory inspection the nature and essence of the technical disclosure of the application. The summary is neither intended to define the invention of the application, which is measured by the claims, nor is it intended to be limiting as to the scope of the invention in any way.

Various advantages and novel features of the present invention are described herein and will become further readily apparent to those skilled in this art from the following detailed description. In the preceding and following descriptions, the various embodiments, including the preferred embodiments, have been shown and described. Included herein is a description of the best mode contemplated for carrying out the invention. As will be realized, the invention is capable of modification in various respects without departing from the invention. Accordingly, the drawings and description of the